# AEROSOL OPTICAL THICKNESS RETRIEVAL OVER LAND: THE ATMOSPHERIC CORRECTION BASED ON THE MERIS L2 REFLECTANCE

**Wolfgang von Hoyningen-Huene(1), Alexander Kokhanovsky(1) , John P. Burrows(1) , Beatrice Berthelot(2) , Peter Regner(3) , and Frederic Baret(4)**

(1) *University of Bremen, Otto-Hahn-Allee 1, D-28334 Bremen, Germany*
(2) *NOVELTIS, Avenue de l'Europe 2, 31520 Ramonville Saint Agne, France*
(3) *ESA ESRIN, Via Galileo Galilei, 00044 Frascati, Italy*
(4) *INRA, Site Agroparc, 84914 Avignon, France*

## ABSTRACT/RESUME

The MERIS L2 reflectance of the data product requires over land surface an atmospheric correction for the aerosol effect. For this purpose the determination of aerosol optical thickness will be done by the BAER (Bremen AErosol Retrieval) approach, modified for this type of data product. Validation and application of the retrieval of spectral aerosol optical thickness and its application for the determination of atmospherically corrected spectral surface reflectance will be demonstrated.

## 1 INTRODUCTION

It is well known that the MERIS L2 data product distributed by ESA does not include the atmospheric correction (AC) over land. AC is performed only over ocean (i.e., Norm.rho_surf – MDS(i) within the L2 data product). Over land surfaces, only the Rayleigh path reflectance and gas absorption are removed from the satellite signal in the official ESA product. This leads to considerable errors in AC for large values of the Aerosol Optical Thickness (AOT). Summing up, the variable aerosol contribution has not been determined over land in the official ESA product. Therefore, the correction for light scattering and absorption by aerosol is not applied within atmospheric correction of the MERIS land products in the operational processing chain. Also the L2 aerosol product, using the dark dense vegetation approach (cfg. Santer, 2000, Santer et al. 1999, 2000 [2][3][4]) is applicable only for very few pixels and don't give the required aerosol information for atmospheric correction.

The completion of the atmospheric correction for land surface products, therefore, requires the determination of aerosol optical thickness for all satellite scenes and its application in the atmospheric correction procedure.

The paper gives a short description of the method of AOT retrieval and the main modifications of BAER for the L2 product. Since the retrieval of AOT cannot be performed for all MERIS channels, over land it is restricted to the short wave channels only, the AOT information must be extrapolated to all 13 MERIS channels, available within the L2 product.

The BAER approach will be implemented within the BEAM tool box, providing users a tool for the determination of AOT over land surface from L2 reflectance data and performing the missing atmospheric correction for the aerosol effect.

## 2 BAER METHOD AND ATMOSPHERIC CORRECTION

For the determination of AOT, the Bremen AErosol Retrieval algorithm (BAER) (von Hoyningen-Huene et al, 2003 [1]) has been modified to account for the conditions of MERIS L2 data over land. Since the reflectance of the L2 product is corrected for Rayleigh scattering, the general equation to be solved for the aerosol retrieval must be changed, removing all terms, containing effects of Rayleigh scattering.

$$\rho_{AER}(\lambda) = \rho_{TOA}(\lambda) - \rho_{RAY}(\lambda) - \frac{T_{1\_AER}(\lambda)\cdot T_{1\_RAY}(\lambda)\cdot T_{2\_AER}(\lambda)\cdot T_{2\_RAY}(\lambda)\cdot A_{SURF}(\lambda)}{1-\rho_{HEM}(\lambda)\cdot A_{SURF}(\lambda)} \quad (1)$$

$\rho_{TOA}$, $\rho_{AER}$, and $\rho_{RAY}$ are the reflectances at top of atmosphere (TOA), for aerosol and for Rayleigh scattering,

Proc. of the MERIS (A)ATSR Workshop 2005, Frascati, Italy
26–30 September 2005 (*ESA SP-597, December 2005)*

$T_1$ and $T_2$ are the total transmissions, considering direct extinction and diffuse scattering, $A_{SURF}$ is the surface albedo, $\rho_{HEM}$ the hemispheric reflectance of the system surface-atmosphere and $\lambda$ is the wavelength.. The removal of the effects of Rayleigh scattering in the L2 product needs only the consideration of aerosol effects not more molecule scattering. For the application with L2 reflectance data equation (1) changes to

$$\rho_{AER}(\lambda) = \rho_{TOA}(\lambda) - \frac{T_{1\_AER}(\lambda) \cdot T_{2\_AER}(\lambda) \cdot A_{SURF}(\lambda)}{1 - \rho_{HEM\_AER}(\lambda) \cdot A_{SURF}(\lambda)} \qquad (2)$$

The variable surface albedo over land is considered by a mixing model of surface reflectance, yielding it as fractions of 'green vegetation' and 'bare soil'. $A_{SURF} = \rho_{SURF} = F$ (NDVI $\rho_{VEG}$ + (1-NDVI) $\rho_{SOIL}$ ). This model is tuned by two parameters, estimated from the satellite scene self: NDVI and a reflectance ratio F for the channel at 0.665 µm. $F = (\rho_{TOA} - \rho^*_{AER})/ \rho^*_{SURF.}$

Finally look-up-tables for the relation of $\rho_{AER}(\lambda)=f(\delta_{AER}(\lambda))$ for a selected aerosol type will be used to transfer $\rho_{AER}$ to $\delta_{AER}$, the AOT.

The described procedure yields the spectral AOT for the short-wave channels of MERIS (channels 1 – 7, 0.412 – 0.665 µm) on a pixel-by-pixel basis. Its application for atmospheric correction of 13 MERIS channels, including the NIR until 0.885 µm requires the extrapolation of AOT to NIR channels.

## 3 RESULTS AND VALIDATION

### 3.1. Retrieval Results

For tests and investigations, scenes over Germany, France, Italy and Spain are used. Within these regions several ground-based sun photometer measurements are operated by AERONET, Holben et al. 1998, 2001 [5][6]. Thus comparisons with ground based data enable us an independent validation of the results for the AOT retrieval.

Since the BAER approach can be applied for wavelength below the red edge of the green vegetation, AOT for 7 short wave channels of MERIS – 0.412 – 0.665 µm can be obtained. This yields the spectral AOT within the range of 0.412 – 0.665 µm. For channels with wavelength larger 0.665 µm the AOT cannot retrieved directly by the BAER approach.

The obtained spectral range over 7 MERIS channels, however is sufficient to derive the Angström $\alpha$-parameter

$$\alpha = \frac{\sum_N \left[(\ln \delta_{AER}(\lambda) - \ln \overline{\delta_{AER}}) - (\ln \lambda - \ln \overline{\lambda})\right]}{\sum_N (\ln \lambda - \ln \overline{\lambda})^2}.$$

An example of AOT, derived by BAER is given in Fig. 1, using the MERIS scene of 11. August 2003 with several forest fire events in Portugal. Cloud pixels are generally flagged. Brighter ground pixels give poor results, manly for channels with wavelength larger 0.510 µm. Therefore also bright pixels are flagged. Investigations are in progress to extend BAER also for brighter grounds.

A selection of spectral AOT is presented in Fig. 2. The polluted spectra are taken from the valley of rivers Ebro and Garonne, the cleanest cases are found in SW Portugal outside of fire plumes. In the spectra of the cleanest cases one can see at the wavelength of 0.560 µm remaining effects of the green vegetation peak at this wavelength. The error of AOT by this disturbance is about 0.03 and not of importance for larger turbidity. A plot of Angström $\alpha$-parameter is given in Fig. 3 showing the expected range.

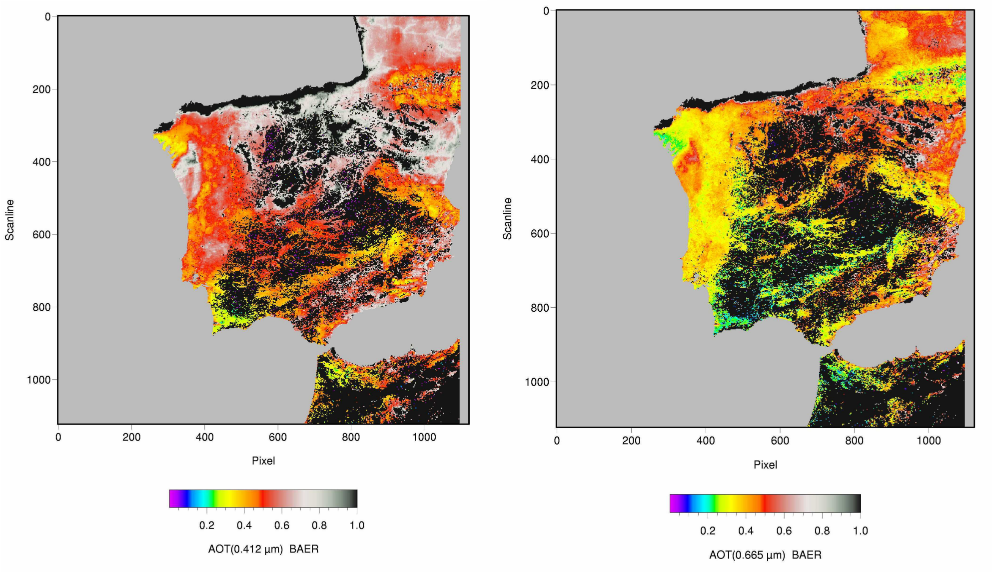


Fig.: 1 Aerosol optical thickness, retrieved by BAER, using L2 data of the MERIS scene of 11. August 2003 over Spain for two wavelength: channel 1 – 0.412 µm (left) – and channel 7 – 0.665 µm (right). Black areas are flagged data (clouds, bright grounds)

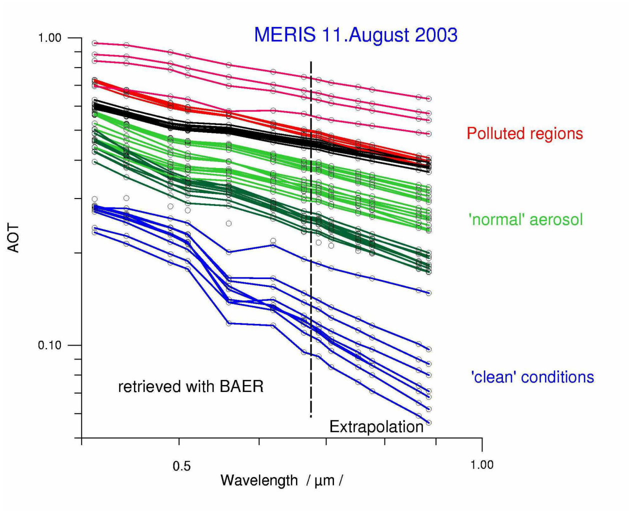


Fig.: 2 Spectral AOT obtained by BAER: Spectra give examples of the range between very polluted and the cleanest cases within the scene of 11. August 2003.

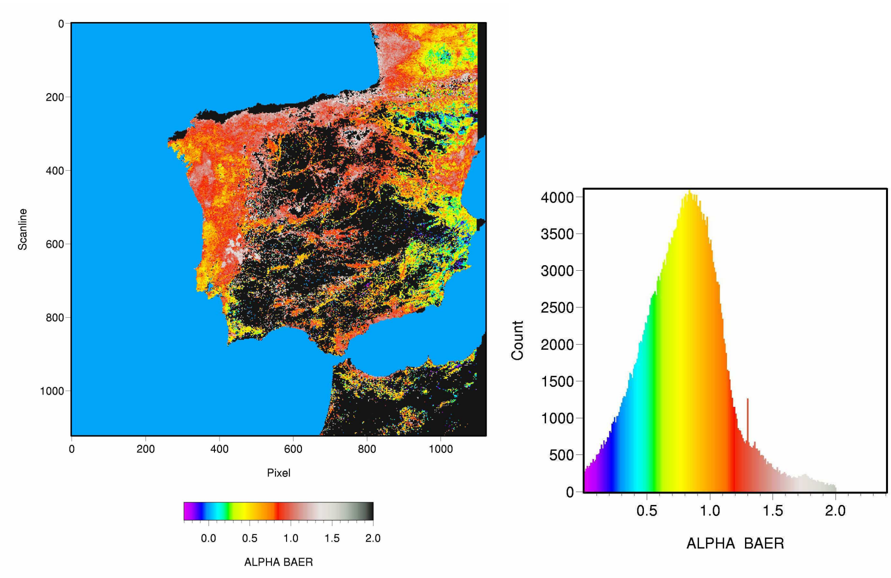


Fig.: 3 Angström $\alpha$-parameter, derived from AOT of 7 short-wave MERIS channels for the scene of 11. August 2003 (left), the histogram of Angström $\alpha$ (right).

## 3.2. Validation

Validation of the AOT results are made (a) by comparison of the retrieval results with ground-based AERONET data and (b) with results of the L2 aerosol product for DDV pixels, if available.

The comparison with ground-based data is made for several MERIS scenes in 2003 over Germany, France, Spain and Italy. AOT retrievals in the vicinity of AERONET instruments have been averaged within a 5 x 5 pixel matrix and the averages are compared with the ground based values. The results mostly agreed within their standard deviations, Fig. 4. The best results for AOT of single channels are obtained for channels 1 – 4. The channel 5 is in some cases disturbed by the variable vegetation peak at 0.55 µm.

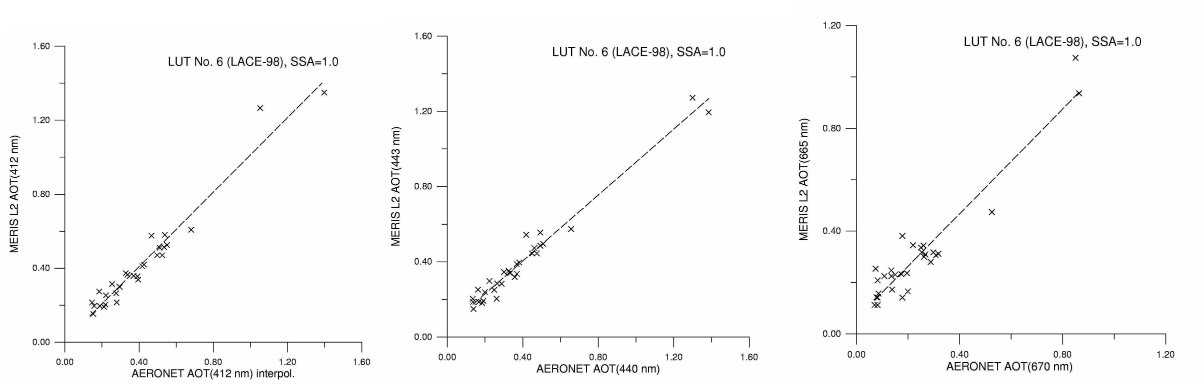


Fig.: 4 Comparison of AOT retrievals over AERONET sites for channel 1, 2 and 7 (0.412, 0.443 and 0.665 µm wavelength).

For comparisons the results of the L2 aerosol product has been used. The L2 product gives the AOT for 0.865 µm and the Angström $\alpha$-parameter. For the comparison with the BAER retrievals the L2 AOT product has been transferred to the wavelength of the BAER retrievals, using Angström power law with the data of the L2 product: $\delta(\lambda) = \delta(0.865\mu m) \cdot \left( \frac{\lambda}{0.865\mu m} \right)^{-\alpha}$.

Since the AOT of the L2 product is obtained with the DDV (dark dense vegetation) approach it is restricted to very dark dense vegetation and inland water areas (cfg. Santer, 2000, Santer et al. 1999, 2000 [2][3][4]). Thus

only few pixel remain for comparisons, Fig.2.

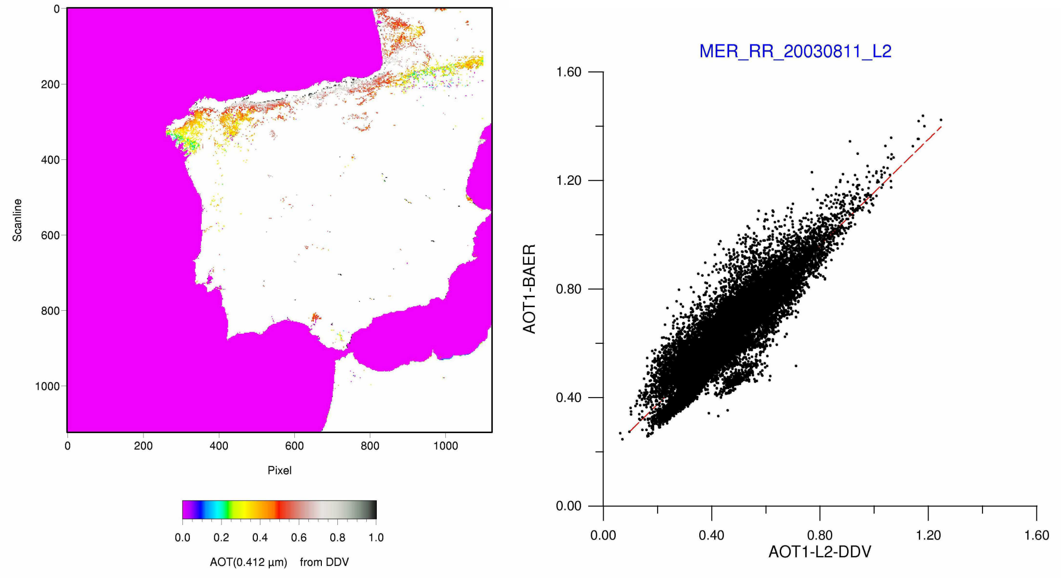


Fig.: 5 AOT for 412 µm, derived from the L2 product (left) and correlation plot with the corresponding BAER results (right). The correlation between both products is $\delta_{BAER} = 0.9767\ \delta_{DDV} + 0.1795$ with a correlation coefficient of r = 0.885 and a standard deviation of $\sigma = 0.073$

Summarizing validation results, the L2 approach of BAER gives well comparable results for AOT and also for the spectral slope in kind if the Angström $\alpha$-parameter. Thus the results can be applied in atmospheric correction schemes.

### 3.4. Atmospheric Correction

For the atmospheric correction within the BEAM tool box the SMAC processor, c.f. Rahman and Dedieu, 1994 [7] is implemented. It uses now the AOT on a pixel-by pixel basis, taking AOT provided by the BAER tool for 0.550 µm. The SMAC processor uses a continental aerosol model and will not consider the spectral properties of AOT, provided by BAER.

However the determination of spectral AOT by BAER enables the extrapolation of AOT for all MERIS channels, using Angström power law: $\delta_{AER}(\lambda) = \delta_{AER}(0.412\ \mu m)\ (\lambda/0.412\ \mu m)^{-\alpha}$. Knowing AOT, equation (2) can be resolved for the determination of the spectral surface albedo, giving the surface reflectance for a Lambert ground. Since the product of $\rho_{HEM\_AER}(\lambda) \cdot A_{SURF}(\lambda)$ is a small number it can neglected for low reflectance and one gets $A_{SURF}(\lambda) \approx \dfrac{\rho_{TOA}(\lambda) - \rho_{AER}(\lambda)}{T_{1\_AER}(\lambda) \cdot T_{2\_AER}(\lambda)}$.

Example for the obtained surface reflectance are below in Fig. 6. Spectra obtained give the spectral characteristics of various surface types from dark forest, types of green vegetation and also drier surface types with less or almost no green vegetation. Spectra of surfaces covered with larger AOT give comparable spectral with surfaces of similar ground with lower AOT. The obtained atmospherically corrected surface reflectance of the channels 0.665 and 0.865 µm is well correlated with the corresponding rectified reflectance of the MERIS L2 product.

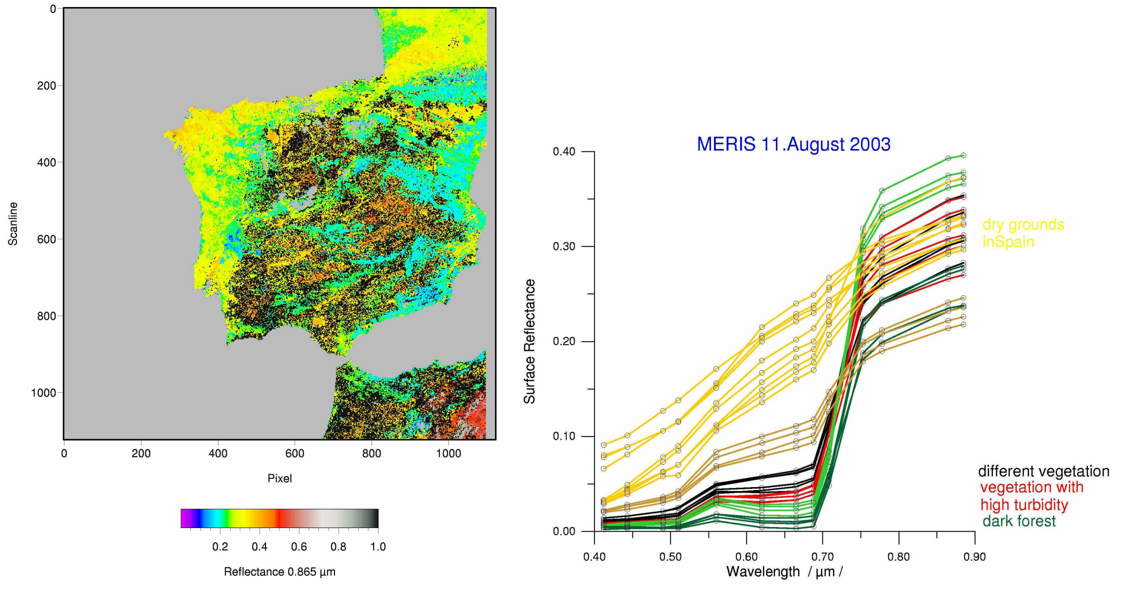


Fig.: 6 Atmospherically corrected surface reflectance for channel 11, 0.865 µm (left), selected spectra of surface reflectance (right)

## 4 CONCLUSION

The presented approach is capable to derive spectral AOT over land. It is in agreement with ground based observation and results of other aerosol products. The obtained spectral AOT enables its application in schemes for atmospheric correction in problems of land surface reflectance determination. It is successfully tested over various regions of Europe.

## 5 REFERENCES

1. von Hoyningen-Huene, W., M. Freitag, and J. B. Burrows: Retrieval of aerosol optical thickness over land surfaces from top-of-atmosphere radiance. J. Geophys. Res., 108(2003), D9 4260, doi:10.1029/2001JD002018, 2003.
2. Santer, R., 2000. Algorithm theoretical basis document : Atmospheric correction over land, MERIS ATBD 2.15. ESA Technical report.
3. Santer, R., Carrere, V., Dessaily, D., Dubuisson, P., Roger, J.-C., 2000. MERIS ATBD 2.15 : Algorithm theoretical basis document, atmospheric correction over land. Technical report PO-TN-MEL-GS-0005, LISE.
4. Santer, R., Carrere, V., Dubuisson, P., Roger, J.-C., 1999. Atmospheric correction over land for MERIS. Int. J. Remote Sensing, 20, 1819–1840.
5. Holben, B.N., Eck, T.F., Tanre, D. Buis, J.P., Setzer, A., Vermonte, E. Reagan, J.A., Kaufman, Y.J., Nakajima, T., Lavenu, F., Jankowiak, I. Smirnow, A.: AERONET-a federal instrument network and data archive for aerosol characterization. 1998 Rem. Sens. Environ., 66,1-16.
6. Holben, B.N., Tanré, D., Smirnov, A., Eck, T.F., Slutsker, I., Abuhassan, N., Newcomb, W.W., Schafer, J.S. Chatenet, B., Lavenu, F., Kaufman, Y.J., Van de Castle, J., Setzer, A., Markham, B., Clark, D., Froin, R., Halthore, R., Karnieli, A., O'Neill, N.T., Pietras, C., Pinker, R.T., Voss, K., Zibordi, G.: An emerging ground-based aerosol climatology: Aerosol optical depth from AERONET. J. Geoph. Res. 106 (2001), 12.067-12.097.
7. Rahman, H., Dedieu, G.: SMAC: a simplified method for the atmospheric correction of satellite measurements in the solar spectrum. Int. J. Remote Sensing, 1994 (15) 1, 123-143.